(12) UK Patent Application (19) GB (11) 2 373 420 (13) A

(43) Date of A Publication 18.09.2002

(21) Application No 0106604.2

(22) Date of Filing 16.03.2001

(71) Applicant(s)
Cambridge Broadband Ltd
(Incorporated in the United Kingdom)
Merlin House, Milton Road, CAMBRIDGE, CB4 0DP, United Kingdom

(72) Inventor(s)
John David Porter
David Benedict Crosby
Stephen David Greaves

(74) Agent and/or Address for Service
Reddie & Grose
16 Theobalds Road, LONDON, WC1X 8PL, United Kingdom

(51) INT CL[7]
H04L 25/03 , H04B 7/26

(52) UK CL (Edition T)
H4P PRE
U1S S2215

(56) Documents Cited
None

(58) Field of Search
UK CL (Edition S) H4P
INT CL[7] H04B , H04L

(54) Abstract Title
Communications system and method

(57) In a method of transmitting a predetermined data sequence from a transmitter (2-1 to 2-n) to a receiver (1) the impulse response of the channel is first determined. The transmitter (2-1 to 2-n) is provided with a pre-distorter having a response which approximates to the inverse of the channel impulse response and comprises a filter having a critical pole. The predetermined data sequence is modified to cause a zero to coincide with the critical pole in the filter and thereby arranged to cancel the pole-zero pair.

This can enable a reductions in the filter length and/or as improvement in its stability.

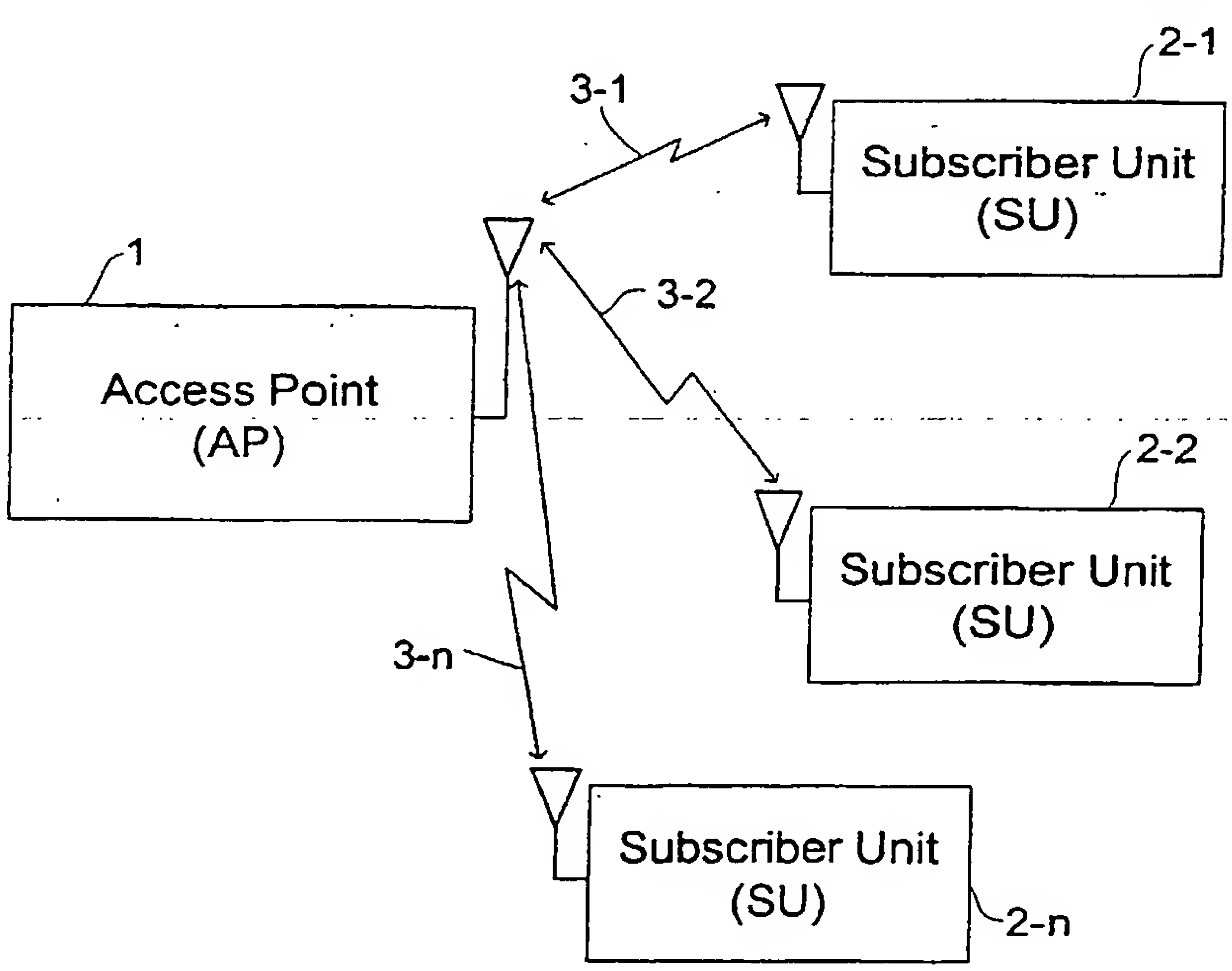

Figure 1

GB 2 373 420 A

At least one drawing originally filed was informal and the print reproduced here is taken from a later filed formal copy.

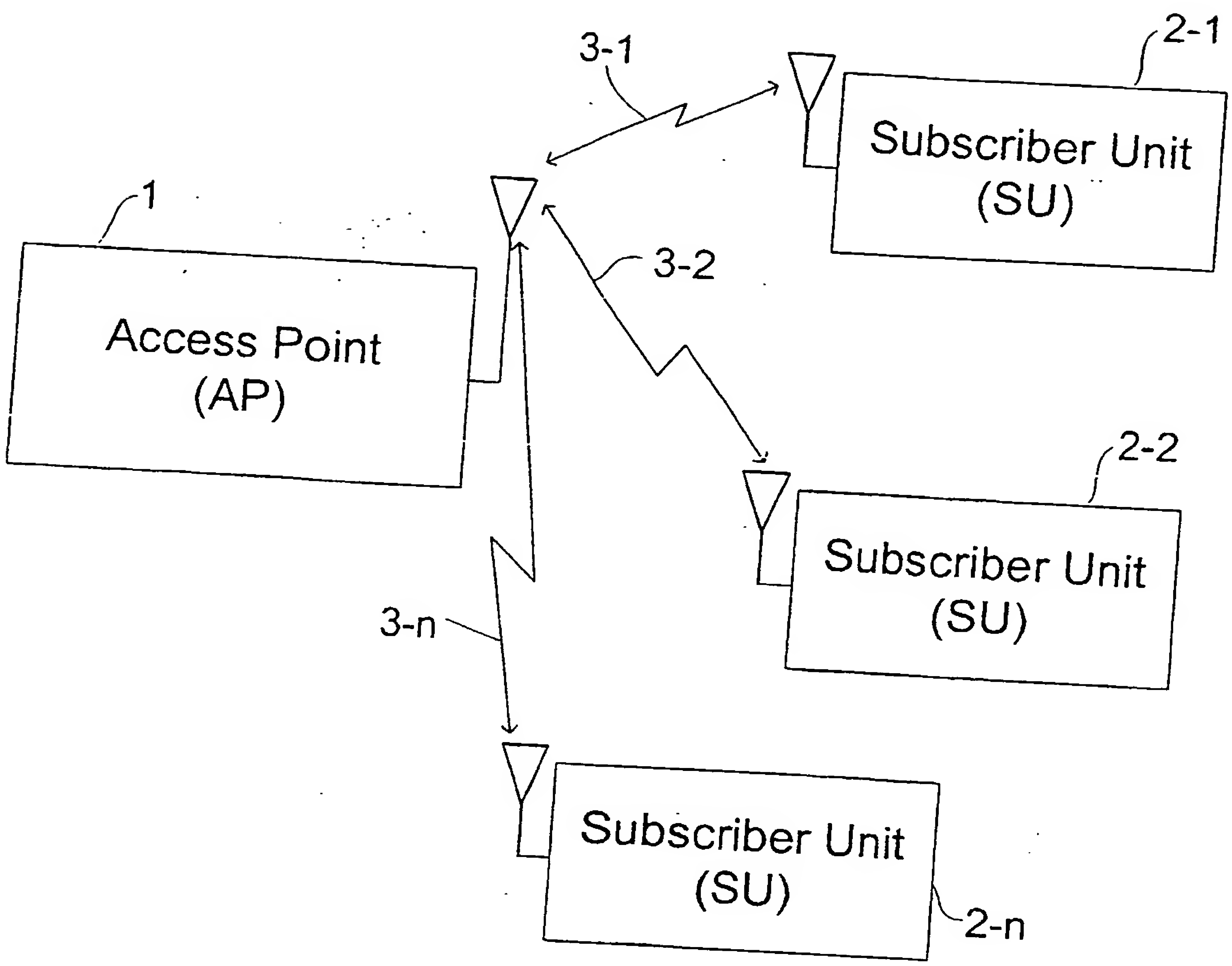
3-1
2-1
Subscriber Unit
(SU)
1
3-2
Access Point
(AP)
2-2
Subscriber Unit
(SU)
3-n
Subscriber Unit
(SU)
2-n

Figure 1

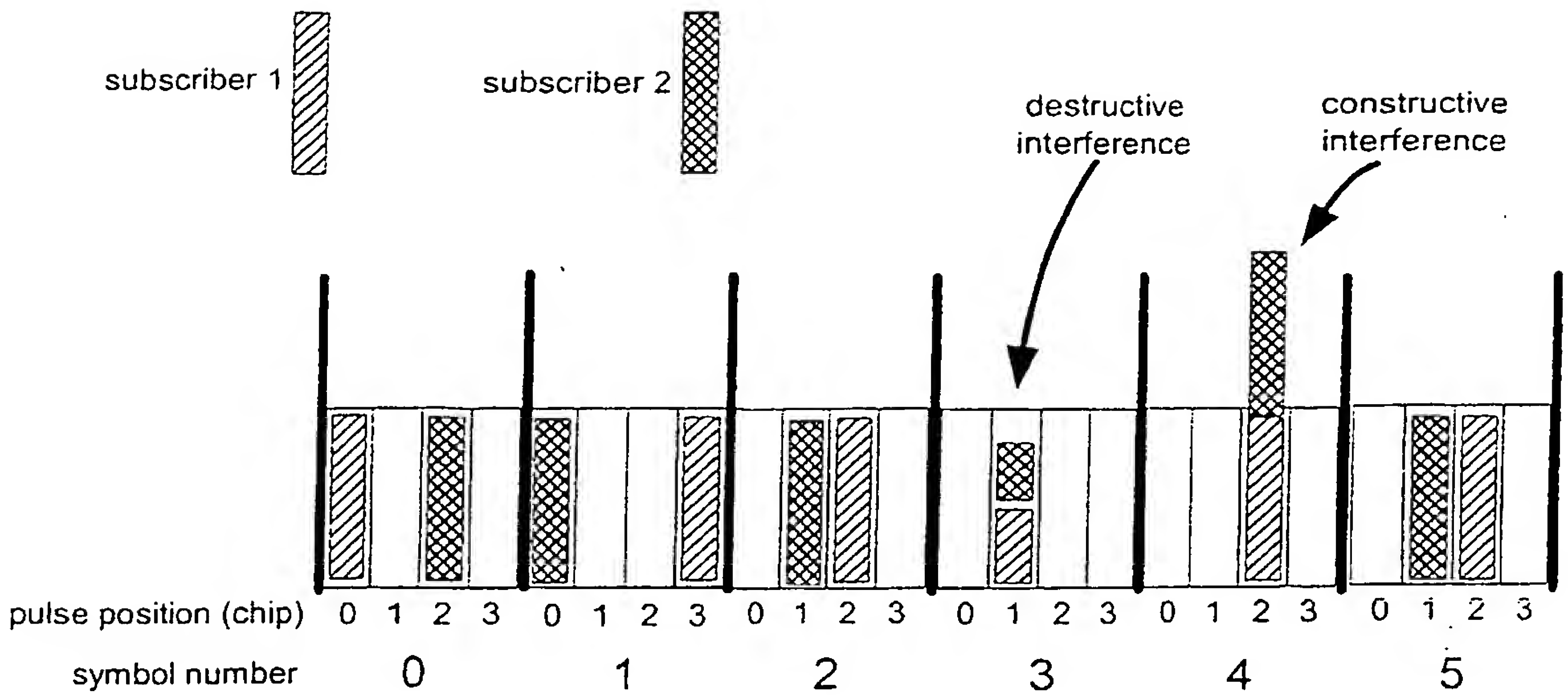

Figure 2

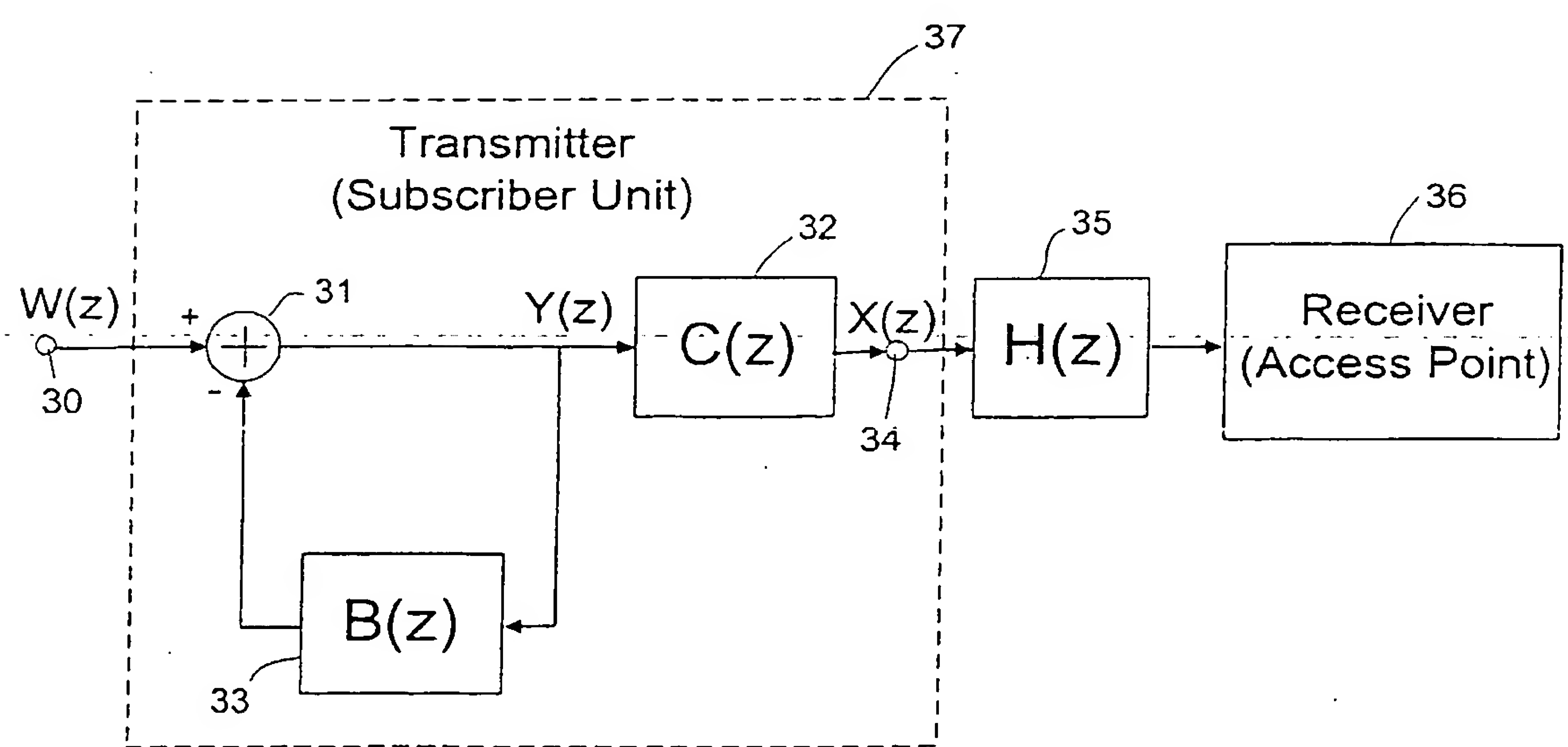

Figure 3

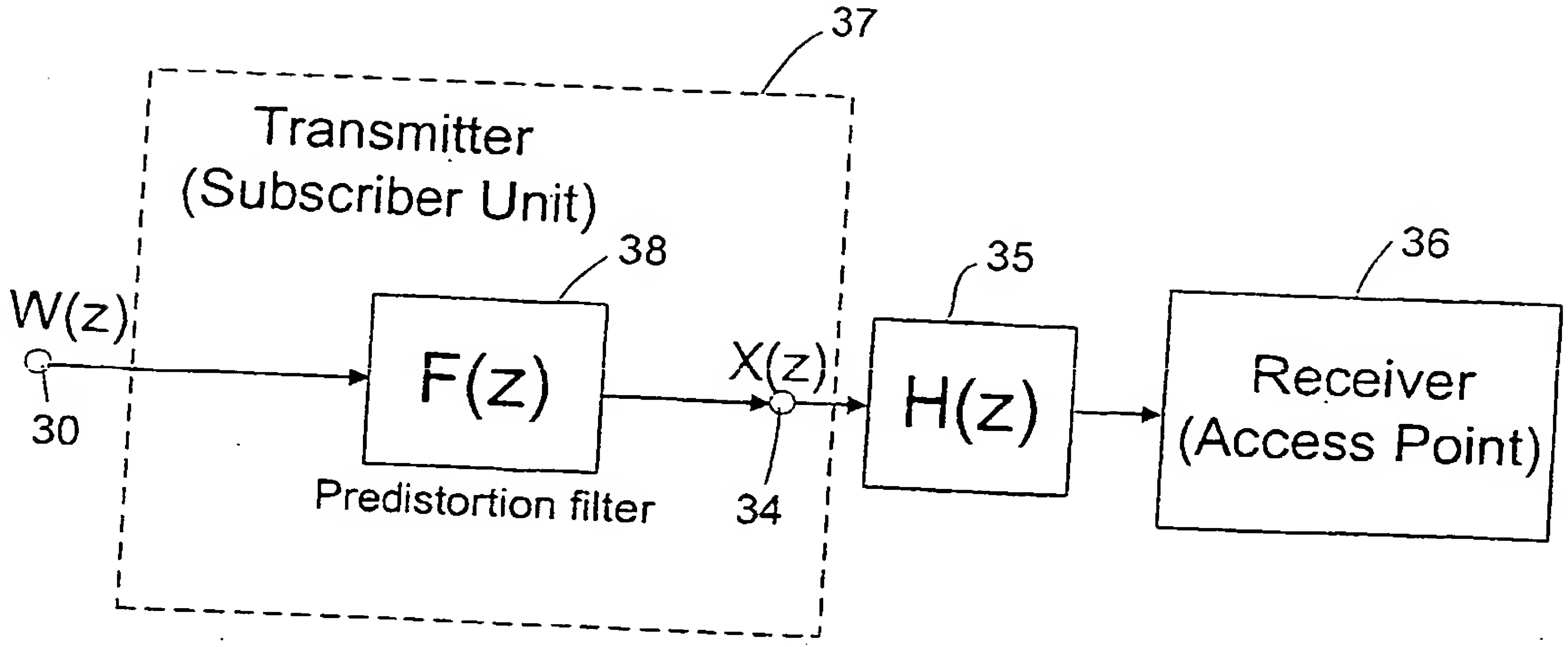

Figure 4

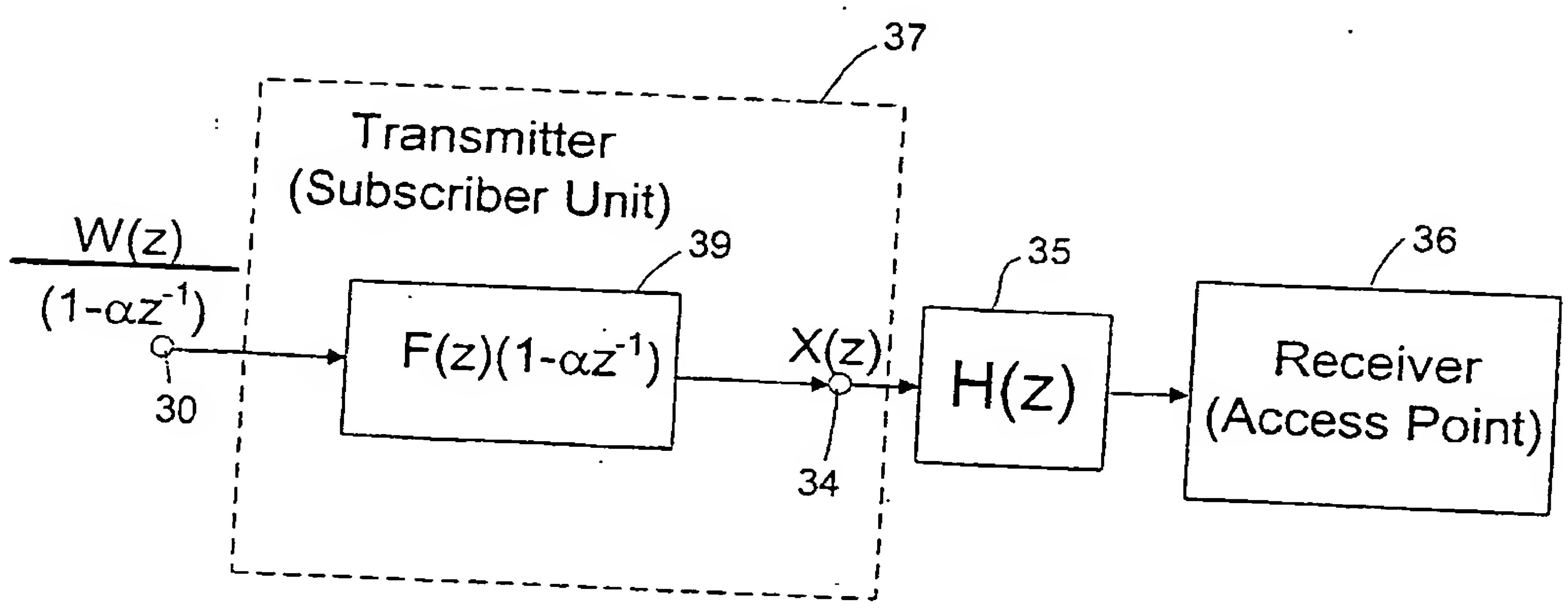

Figure 5

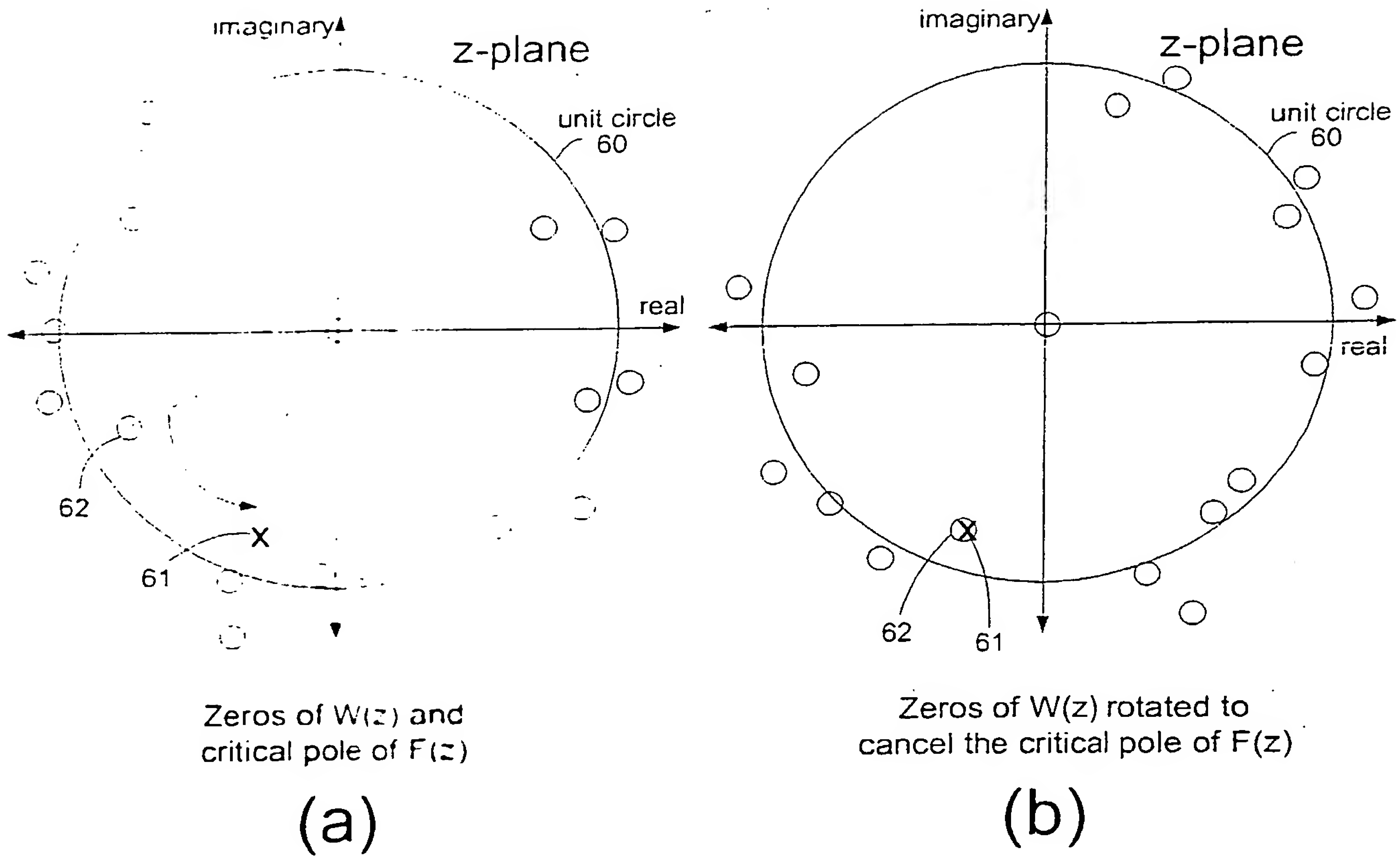
imaginary
z-plane
unit circle
60
real
62
61
Zeros of W(z) and
critical pole of F(z)
(a)
imaginary
z-plane
unit circle
60
real
62
61
Zeros of W(z) rotated to
cancel the critical pole of F(z)
(b)

Figure 6

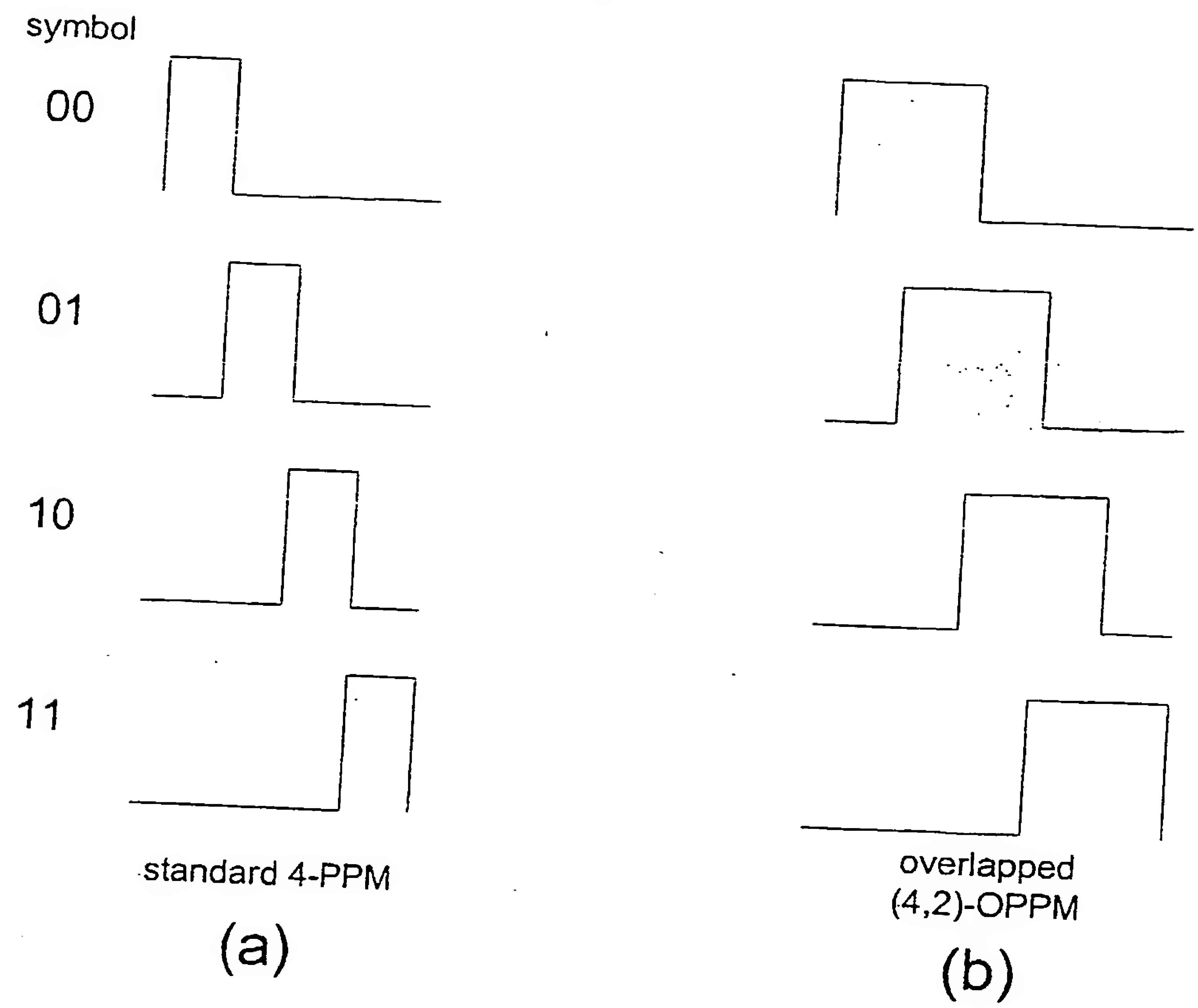

Figure 7

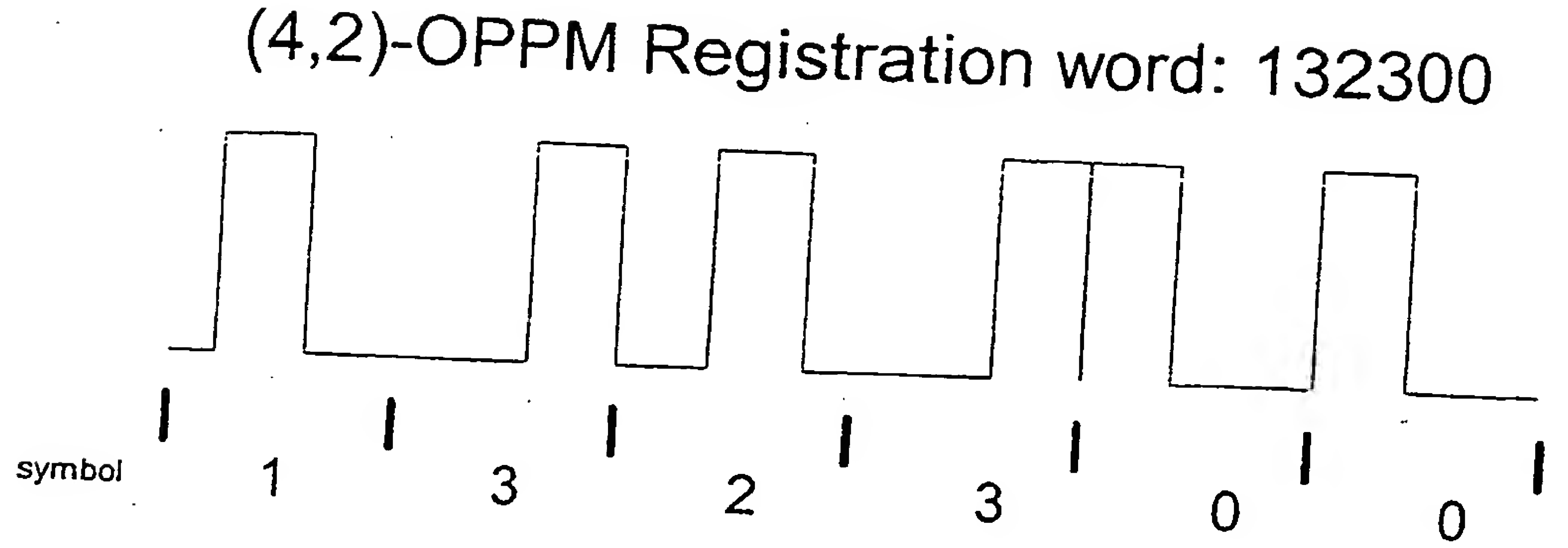

Figure 8

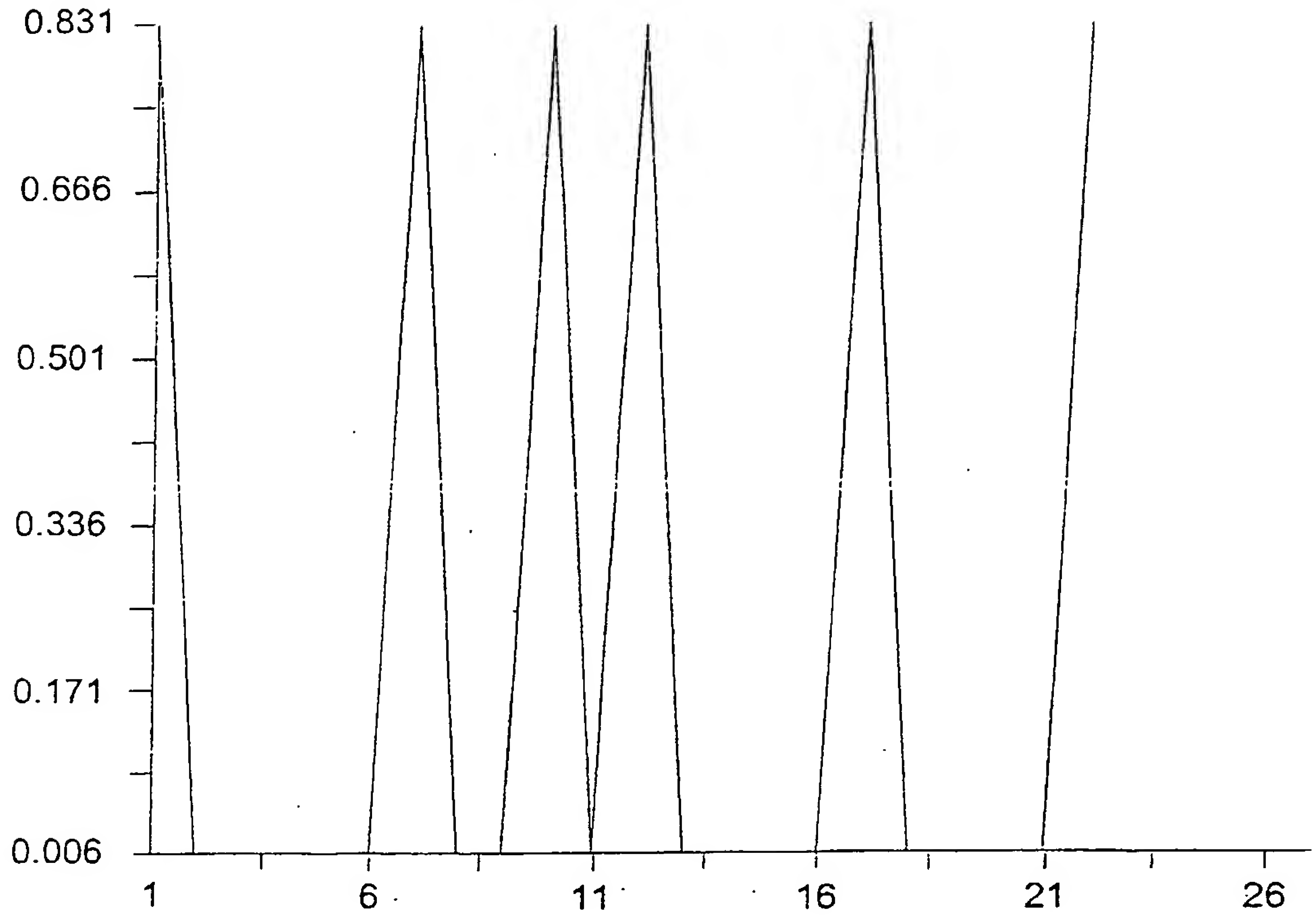

Figure 9a

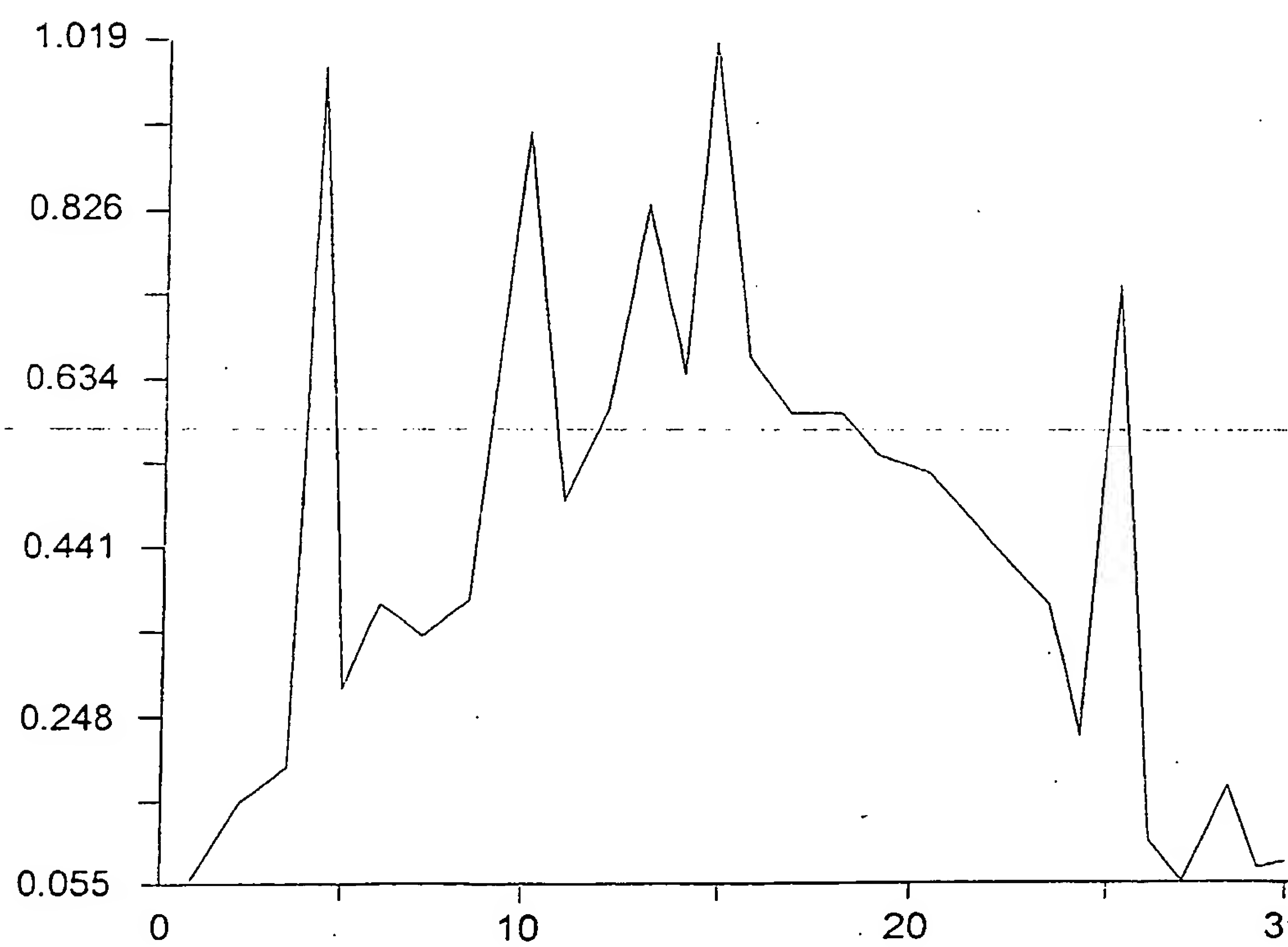

Figure 9c

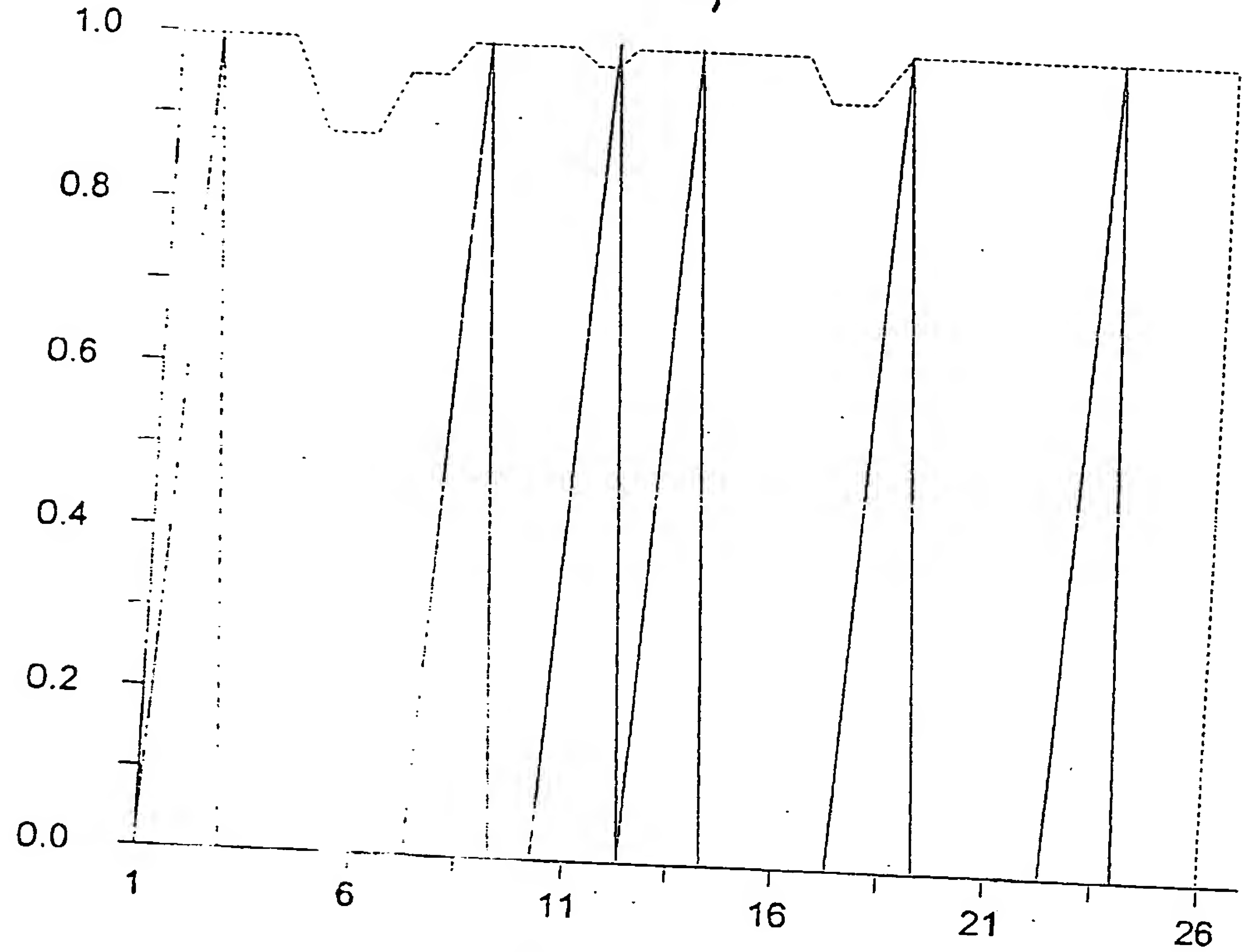

Figure 9b

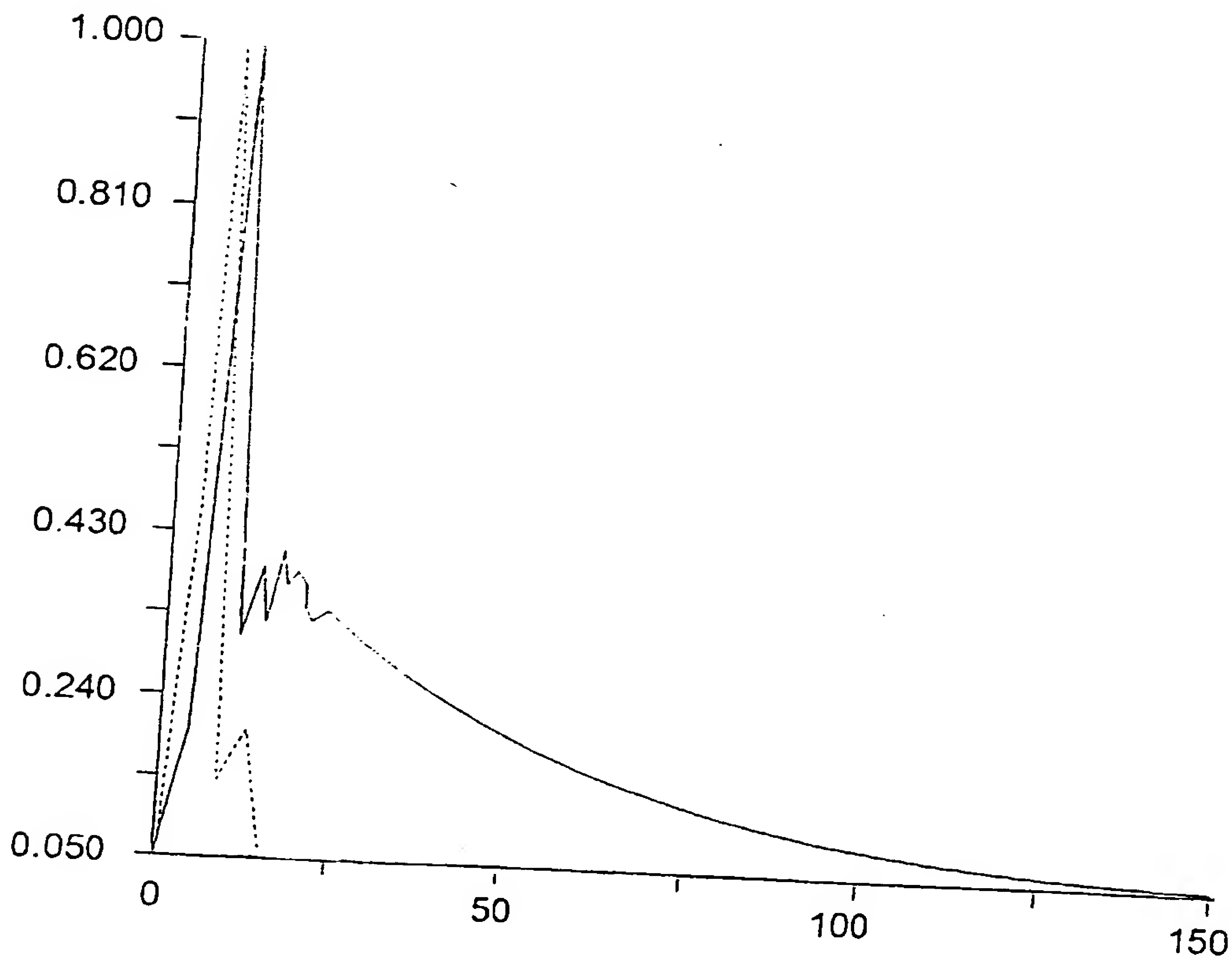

Figure 9d

2373420

13.03.01

42559 GB

Communication System and Method

The invention relates to a method of transmitting a predetermined data sequence to a receiver. The invention further relates to a communication system in which such a method is used and to a transmitting unit for transmitting such a predetermined data sequence to a receiver.

In wireless point to multipoint transmission systems, a number of users communicate with a central station called an access point (AP). All the users called subscriber units (SU) communicate with the AP over a shared common transmission medium. Wireless communication is inherently a broadcast process and consequently, only one SU can communicate with the AP at any one time if interference between SU transmissions is to be avoided. As a result, a mechanism has to be provided to share access to the AP via the common transmission channel in a fair and efficient manner.

In practice, the information transmitted from the SUs to the AP occurs in bursts and the most efficient way of sharing access to the common channel is by random access techniques. A random access scheme provides each SU with the maximum flexibility in gaining access to the channel whenever information is to be sent. There are a number of commonly used random access schemes which includes ALOHA and Slotted ALOHA. A consequence of using random access schemes is that it is inevitable that more than one SU may desire to transmit information at a given time. As a

result, the SUs have to contend for channel access if collision is to be avoided between the transmissions arriving at the AP.

Each SU contends for channel access by transmitting a unique identifier called a contention word to the AP in a known contention frame. By examining the received signal, the AP can determine if more than one SU is contending for the channel at a given time. If only one SU requires access, the AP decodes the SU identifier and allocates an upcoming data frame to that SU.

One consequence of this contention mechanism is that the AP cannot equalise the received contention word since equalisation at the AP would require knowledge about which particular SU is transmitting, which is something the contention mechanism is trying to establish. Consequently, any channel equalisation has to take place at the SU before the transmission of the contention word takes place. The use of equalisation prior to signal transmission is commonly called pre-distortion.

The pre-distorter may comprise a feed forward and feedback filter in reverse order to those in a standard decision feedback equaliser. Unlike the decision feedback equaliser, however, the stability of the pre-distorter is not guaranteed. This is because a decision feedback equaliser incorporates a decision device in the feedback loop which acts to limit the amplitude of the signal into the feedback filter. In a pre-distorter, no decision device is present and the signal into the feedback filter is unbounded and therefore the feedback filter is potentially an unstable element.

One technique used to calculate the coefficients of the feed forward and feedback filters is root allocation. This technique allows a zero forcing pre-distorter to be realised for an arbitrary channel response. The procedure relies on separating the zeros of the channel impulse response into those that fall inside and those that fall outside of the unit circle. The root allocation technique has certain problems when zeros of the channel lie on, or in close proximity to, the unit circle. If the so called critical zeros lie close to but inside the unit circle, then they appear as underdamped roots in the feedback filter transfer function and can lead to instability. If critical zeros lie just outside the unit circle, then these are absorbed into the feed forward filter transfer function and may result in a very long feed forward filter.

The invention provides a method of transmitting a predetermined data sequence to a receiver over a transmission channel comprising the steps of;

a) determining the impulse response of the channel,
b) providing a pre-distortion arrangement at the transmitter, having a response that approximates to the inverse of the channel response, the pre-distortion arrangement comprising a filter having a critical pole,
c) causing a zero of the predetermined data sequence to coincide with the critical pole of the filter; and
d) cancelling the zero of the data sequence and critical pole from the filter.

By using this method, a critical zero can be removed from the feed forward filter transfer function and enable a shorter feed forward filter to be realised. Thus, in the context of sending a contention word, which is a known data sequence for a given transmitter, the transmitter can be arranged so that the filter in the pre-distortion arrangement has a minimum length.

Step c) of the method may be performed by modifying the phase of the zeros of the predetermined data sequence. This technique is referred to in this application as root rotation.

In a particular embodiment, the unique contention word ascribed to each SU consists of 24 chips. These 24 chips convey a unique customer identifier to the access point and are transmitted as a succession of six pulse position modulation (4-PPM) symbols of length four. Consequently, only one chip in every slot of four chips is high and there exists 4^6 which equals 4096 distinct identification words. These identification words are amplitude encoded only and consequently, no information is carried in their phase. As a consequence, the phase of the contention word maybe varied without altering the information at the receiver. This enables the zero of the contention word to be aligned with a critical pole of the filter.

It is possible to remove more than one critical pole if the encoding of the contention word is slightly modified, although still retaining its PPM based structure. In particular, the coding is changed from PPM to overlapped

pulse position modulation (OPPM). This OPPM scheme, together with some simple polynomial constructions, can enable the removal of two or more critical poles. In particular, (4,2) OPPM can be used to remove an additional critical pole, whilst (4,4) OPPM enables the removal of two critical poles in addition to the critical pole removed by root rotation.

The invention further provides a transmitter for transmitting a predetermined data sequence to a receiver over a transmission channel, the transmitter comprising a pre-distortion arrangement having a response that approximates to the inverse of the channel response, the pre-distortion arrangement comprising a filter having a critical pole removed by causing a zero of the predetermined data sequence to coincide with the critical pole of the filter and cancelling the pole-zero pair, and means for transmitting the predetermined data sequence modified by the pre-distortion arrangement.

Alternatively, or in addition, when the predetermined data sequence comprises n chips of pulse position modulated (PPM) symbols of length b and the PPM symbols are encoded in overlapped pulse position modulated (OPPM) form as (b,c)-OPPM symbols, where c is an integer greater than one, the phase of the pulse shape of the OPPM symbol may be modified so that a zero of the pulse shape coincides with a critical pole of the filter and the filter characteristic is modified by cancelling the pole-zero pair.

The above and other features and advantages of the invention will be apparent from the following description,

by way of example, of an embodiment of the invention with reference to the accompanying drawings in which:

Figure 1 shows a communication system according to the invention,

Figure 2 illustrates the contention process between two subscriber units seeking access to the access point,

Figure 3 shows a pre-coder for use in the SUs of Figure 1,

Figure 4 illustrates a general pre-distorted communication system,

Figure 5 is a modification of the system of Figure 4 in which one method according to the invention is illustrated,

Figure 6 shows the zeros of a predetermined data sequence and a critical pole of the pre-distortion filter,

Figure 7 shows the format of PPM and (4,2)-OPPM symbols,

Figure 8 shows a predetermined data sequence encoded as (4,2)-OPPM symbols, and

Figure 9 shows the predetermined data sequence before root rotation, after root rotation, and after passing through the pre-distortion filter, and shows the filter length before and after critical pole removal.

Figure 1 shows in block schematic form a wireless point to multipoint transmission system. In this embodiment the transmission is frequency division duplex (FDD), that is the AP transmits on one frequency and the SUs transmit on a different frequency, and adaptively modulated either as QPSK or QAM depending on the distance, transmitter power, and quality of the radio link. The traffic is managed by time division multiple access. As shown in Figure 1 a number of users communicate with a central station 1. The central station 1 is referred to as an access point (AP).

The users communicate with the AP by means of subscriber units (SU). A plurality of subscriber units 2-1, 2-2, ... 2-N are provided for N users. The subscriber units communicate with the AP via transmission paths 3-1, 3-2, ... 3-N.

Wireless communication is inherently a broadcast process and consequently only one SU can communicate with the AP at any one time if interference between SU transmissions is to be avoided, since the SUs all transmit at the same frequency. Therefore, a mechanism is provided to share access to the AP via the common transmission channel in a fair and efficient manner. In practice, the information transmitted from the SU to the AP occurs in bursts, since an SU will only transmit when a subscriber wishes to communicate, and the most efficient means of sharing access to the common channel is by random access techniques. A random access scheme provides each SU with maximum flexibility in gaining access to the channel whenever information is to be sent. A consequence of using random access schemes is that contention for channel access between SUs invariably occurs. That is, more than one SU may wish to transmit information at a given time and hence, these SUs must contend for access to the channel if a collision is to be avoided between the transmissions arriving at the AP.

In the present embodiment, each SU contends for channel access by transmitting a unique identifier called a contention word to the AP in a known contention frame. By examining the received signal, the AP can determine whether more than one SU is contending for the channel. If only one SU requires access, the AP decodes the SU

identifier and allocates an upcoming data frame to that SU.

The unique contention word assigned to each SU consists of 24 chips transmitted as QAM symbols. These 24 chips convey a unique concustomer identifier to the access point and are transmitted as a succession of six pulse position modulation (4-PPM) symbols of length four. Consequently, only one chip in every slot of four chips is high and there exists $4^6 = 4096$ distinct registration words. That is, a twelve-bit identifier. The registration word is amplitude encoded only and no information is carried in the phase. Other SUs maybe simultaneously contending for access to the channel. The PPM format of the contention word allows the access point to detect the presence of two or more contending users. One consequence of this contention mechanism is that the AP cannot equalise the received contention word since equalisation at the AP would require knowledge about which particular SU is transmitting and this is something the contention mechanism is trying to establish. Consequently, any channel equalisation has to take place at the SU before transmission of the contention word takes place. The use of equalisation prior to signal transmission is commonly called pre-distortion but may also be referred to as pre-coding.

Figure 2 illustrates a contention frame where two subscribers are both contending for access. Subscriber 1 has the identifier 043233 while subscriber 2 has the identifier 202231. It will be seen that the AP can detect that there are two chips high in at least some of the four chip slots and can use this information to determine that

more than one subscriber is seeking access at a particular time. In this case, the AP will not know which two subscribers are contending merely that there are two contending subscribers at the same time and consequently, neither will be allocated a transmission channel. Clearly if two SUs are contending for a transmission channel there must be a difference between the two unique identifiers otherwise they would not be unique. Consequently, at least one of the six time slots will have more than one high chip. Even where the high chips coincide in a time slot, it is likely that either constructive or destructive interference will produce an input amplitude to the AP which is significantly above or below the average level. This forms another mechanism for the AP to detect that more than one SU is seeking a transmission channel.

Figure 3 shows the general arrangement for pre-distorting or pre-coding the contention word at the SU. The pre-codes comprises an input 30 which is connected to a first input of a summing arrangement 31 whose output is connected to the input of a feed forward filter 32 and to the input of a feedback filter 33. The output of the feedback filter is connected to a second input of the summing arrangement 31 while the output of the feed forward filter 32 is connected to an output 34 of the pre-coder. The pre-coder comprises a feed forward (FF) 32 and feedback (FB) 33 filter in reverse order to those in a standard decision feedback equaliser (DFE). However, unlike the DFE, the stability of the pre-coder is not guaranteed. This is because a DFE incorporates a decision device in the feed back loop which acts to limit the amplitude of the signal into the feedback filter. In a pre-coder, no decision device is present and the signal

into the feedback filter is unbounded and therefore, the feedback filter is potentially an unstable element. One technique used in calculating the coefficients of the feed forward and feedback filters is root allocation. The root allocation technique allows a zero forcing pre-coder to be realised for an arbitrary channel response. The procedure relies on separating the zeros of the channel impulse response into those that fall inside and those that fall outside the unit circle. For an estimated channel impulse response which has a z-transform H(z) root finding is used to factorise H(z) into two components as follows;

$$H(z) = H_1(z)H_2(z)$$

where $H_1(z)$ consists of all the routes of H(z) lying inside the unit circle (stable roots) and $H_2(z)$ consists of all the roots of H(z) lying outside the unit circle (unstable roots).

A new polynomial $H_3(z)$ is formed by reversing the order of the coefficients of $H_2(z)$.

$$H_2(z) = [h_o z^{-n} + h_1 z^{-n+1} + \ldots\ldots + h_{n-1} z^{-1} + h_n]$$
$$H_3(z) = [h_n z^{-n} + h_{n-1} z^{-n+1} + \ldots\ldots + h_1 z^{-1} + h_o]$$

The polynomial $H_3(z)$ has routes at the reciprocal locations to the routes of $H_2(z)$. The feedback filter 33 of the pre-coder is set equal to

$$B(z) = [H_1(z)H_3(z)] - 1$$

The feed forward filter 32 of the pre-coder is set equal to

$$C(z) = \frac{H_3(z)}{H_2(z)}$$

Note that the FIR filter C(z) must be implemented with a delay resulting in a stable but non-causal filter. The overall transfer function of the pre-coder is

$$\frac{W(z)}{X(z)} = \frac{1}{H_1(z)H_3(z)}\frac{H_3(z)}{H_2(z)}$$
$$= \frac{1}{H_1(z)H_2(z)}$$
$$= \frac{1}{H(z)}$$

Since the transfer function $\frac{1}{H_1(z)\ H_3(z)}$ has all its roots inside the unit circle the feedback filter is now stable. The disadvantage with this root allocation method is that it is not always possible to cleanly separate the zeros of H(z) into those outside the unit circle and those inside the unit circle. Many channels have some zeros lying on or very close to the unit circle. These zeros near the unit circle are sometimes known as critical zeros. Critical zeros cause problems with root allocation because they result in an unstable feedback filter if they are placed in the feedback filter transfer function or else require a very long feed forward filter if placed in the feed forward filter transfer function. This problem has made the root allocation method unsuitable for channels with critical zeros.

An alternative to the root allocation method is to use the minimum mean square error (MMSE) algorithm to determine

- 12 -

the feedback and feed forward filter coefficients. The main problem with this approach is that while the MMSE algorithm operates to minimise the impact of intersymbol interference and noise it does not necessarily provide a stable implementation for the feedback filter. Specifically the zeros of the feedback filter are not always located within the unit circle. In this case the magnitude of the input to the feedback filter will increase exponentially with time irrespective of the length of the input sequence. One indicator of an unstable feedback filter implementation is the presence of any feedback filter coefficients with a magnitude larger than unity. An unstable implementation can, however, still result even when all the feedback filter coefficients have a magnitude smaller than unity and the only definite means of identifying feedback filter instability is to determine the exact location of the zeros of the feedback filter polynomial, that is root finding.

It is possible to obtain a stable single filter implementation for the pre-distorter by calculating the overall transfer function of the combined feed forward and feedback filters.

The combined transfer function of the FF and FB filters for both pre-distortion methods is given by:

$$F(z) = \frac{Y(z)}{X(z)} = \begin{cases} \dfrac{1}{H(z)} & \text{Root Allocation} \\[2ex] \dfrac{C(z)}{1 - B(z)} & \text{MMSE Algorithm} \end{cases}$$

The denominator of F(z) may be written as the product of two polynomials $D(z) = D_1(z)\, D_2(z)$, where $D_1(z)$ only has zeros inside the unit circle and ($D_2(z)$ has zeros on or outside the unit circle. The pre-distortion filter now has a transfer function of;

$$F(z) = N(z)\frac{1}{D_1(z)}\frac{1}{D_2(z)}$$

A polynomial expansion for $\frac{1}{D_1(z)}$ can be calculated readily by long division.

The expansion of $\frac{1}{D_2(z)}$ is, however, less straight forward. This is because the zeros of $D_2(z)$ can lie outside the unit circle and under those circumstances long division results in a polynomial with unbounded coefficients. A stable implementation can, however, be obtained by reversing the coefficients of $D_2(z)$ before performing the long division, and then reversing the coefficients of the resulting quotient afterwards. This procedure is explained, for example, in the textbook entitled Equalizer for Digital Modems by A.P. Clark, published by Pentech Press Ltd ISBN 0-7273-0504-2 at pages 169-173. The final polynomial expression for F(z) is obtained by multiplying N(z) by the polynomial expression for $\frac{1}{D_1(z)}$ and $\frac{1}{D_2(z)}$ obtained through long division.

Any critical zeros act to increase the length of F(z) (in fact F(z) will have infinite length if any zero is located on the unit circle).

It has been shown that pre-distortion based on either root finding or the MMSE algorithm suffer from two problems which arise because of the presence of critical roots. First, the length of the pre-distortion filter approaches infinity as any of the roots of the channel impulse response approach unity and, secondly, the amplitudes of the signal out of the pre-distortion filter may become large. The present invention provides a method of eliminating critical zeros in the filter characteristic. This is achieved by taking advantage of the key properties of the registration word, that is it has finite length and is not phase sensitive. These properties are utilised to force pole zero cancellation between the pre-distortion filter and the registration word thereby removing a number of critical zeros.

Figure 4 illustrates a general pre-distorted transmission system. The pre-distortion filter F(z) if calculated according to the root allocation algorithm will have a response which approximates to the inverse of the channel response H(z). The filter F(z) is assumed to have a length n and to have (n-1) poles which correspond to the positions of the zeros of H(z). That is,

$$F(z) = \frac{1}{(1-a_1 z^{-1})(1-a_2 z^{-1})(1-a_3 z^{-2})\ldots(1-a_{n-1} z^{-n+1})}$$

Where $a_1, a_2, \ldots, a_{n-1}$ are the poles of F(z) (and hence the zeros of H(z)).

The input registration word W(z) has a length m with a z-transform

$$W(z) = w_0 + w_1 z^{-1} + \ldots + w_{m-1} z^{1-m}$$

It should be noted that because of the PPM nature of the registration word most of the coefficients will be zero and those that are non-zero will have an amplitude of unity.

W(z) may alternatively be expressed in terms of its zeros

$$W(z) = (1 - w_1 z^{-1})(1 - w_2 z^{-1})(1 - w_3 z^{-2})\ldots(1 - w_{m-1} z^{-m+1})$$

Where the w_1, w_2, ...w_{m-1} are the zeros of W(z).

If it is assumed that zero of W(z) occurring at $z=\alpha$ also appears as a pole in F(z) then the above system will have the same performance as a system shown in Figure 5 where the input registration word has a length (m-1) and is given by $\frac{W(z)}{1-\alpha z^{-1}}$ and the pre-distortion filter now has the transfer function $F(z)(1-\alpha z^{-1})$. It can be seen that this process has removed a pole from F(z) and a zero from W(z). If the pole removed from F(z) happens to be a critical pole then it may be possible to reduce the length of the resulting pre-distortion filter such that the length of a pre-distortion filter given by $F(z)(1-\alpha z^{-1})$ may have a significantly reduced length. The following description discloses two techniques for the removal of critical poles from the pre-distortion filter by pole zero cancellation.

The first technique which may be called root rotation removes one critical zero by modifying the phases of all the zeros of the registration word. Figure 6a shows the zeros of an example registration word corresponding to the

polynomial $W(z)=z^{-1}+z^{-7}+z^{-10}+z^{-12}+z^{-17}+z^{-22}$. This polynomial corresponds to the 4-PPM symbol sequence [132012]. The

resulting 17 zeros can be seen to be located in close proximity to the unit circle. If it is assumed that the pre-distortion filter has a transfer function F(z) which has a critical pole at $z=\alpha$ and which is shown as a cross 61 in Figure 6 it is necessary to generate a zero at the same location in W(z) in order to remove this critical pole from F(z). This is achieved by rotating all the zeros of W(z) around the origin until one, that is zero 62, happens to fall in close proximity to the critical pole that is to be cancelled. The coincident pole zero pair can then be removed from the appropriate transfer functions without affecting the overall performance. Figure 6b illustrates the superposition of the zero 62 on the pole 61.

It may be noted that because all the zeros of W(z) are rotated by the same amount this process of root rotation ensures that the peak amplitude of the root rotated W(z) is still amplitude limited to unity. In general only a single critical pole may be removed from the transfer function F(z) of the pre-distortion filter using this technique as it is unlikely that further zeros of the data word will coincide with a pole of the pre-distortion filter by rotating the data word by a given amount.

For the example above, the registration word after root rotation and removal is given by:

$$\frac{W(z)}{(1-ae^{j\phi}z_{-1})}=(1-e^{j\phi}w_1z^{-1})(1-e^{j\phi}w_2z^{-1})(1-e^{j\phi}w_3z^{-2})\ldots(1-e^{j\phi}w_{m-2}z^{-m+2})$$

where it has been assumed the (m-1)th zero has been

removed by the root rotation process, w_1 are the roots of W(z) and ϕ is the angle of rotation.

To illustrate this further, Figure 6 shows the results of pole-rotation for an example Rician channel of:

$$H(z)=0.124+0.106z^{-1}+0.816z^{-2}+0.167z^{-3}+0.211z^{-4}$$
$$+0.154z^{-6}=0.153z^{-7}+0.167z^{-8}+0.055z^{-9}$$

This channel has a Rician K factor of 2.0 and a critical zero located just inside the unit circle (the magnitude of the critical root is 0.989). Figure 9b shows the magnitude of the registration word before (solid line) and after (dashed line) root rotation and removal has taken place. Note that the registration word after root rotation, although still amplitude limited to unity, bears little resemblance to the original word. After passing this root rotated word through the pre-distortion filter the signal in Figure 9c results. The received signal is shown in Figure 9a. As expected, the root rotation and removal process has not affected the amplitude information of the received signal. Figure 9d shows the impulse response of the pre-distortion filter (dashed line) when root rotation and pole-zero cancellation has taken place. Also shown is the impulse response of the pre-distortion filter impulse response when root rotation and pole-zero

cancellation is not used (solid line). This subfigure dramatically illustrates the benefits which may be achieved using pole-zero cancellation schemes depending on the particular transfer functions of the filters and characteristics of the applied signal. With the application of pole-zero cancellation, the length of the impulse response of the pre-distortion filter has reduced from 148 samples to a mere 9 samples when causing the impulse response to fall to 5% of the peak values.

If it is desired to remove more than one critical pole, it is possible to do so by modifying the encoding of the registration word slightly whilst still retaining its PPM based structure. In particular, if the encoding is changed from PPM to overlapped pulse position modulation (OPPM) by using some simple polynomial constructions two or more critical poles may be removed.

The format of the (L,N)-OPPM symbol is shown in Figure 7b for the case of L=4 and N=2. Also shown as Figure 7a is the symbol set for a standard 4-PPM symbol. Both formats convey two bits of information by transmitting one of L possible symbols. More precisely in both PPM and OPPM the information is conveyed by the position of the first high chip. However, in (L,N)-OPPM the length of the high section of the signal is increased to N chips in duration. To avoid overlap between adjacent symbols this extension requires increasing the size of the OPPM symbol to (L+N-1) chips. For the example shown, this means that the (4,2)-OPPM symbol requires one more chip per symbol than 4-PPM. Figure 8 shows an example of a (4,2)-OPPM based registration word corresponding to the identification code

132300. This longer OPPM symbol length increases the total length of the registration word by 6(L+N-1) chips. The final length in chips for various OPPM formats is given in the table below.

PPM SCHEME	Registration Word Length (chips)	Number of Poles removed
4-PPM	24	0 (1)*
(4,2)-OPPM	30	1 (2)*
(4,3)-OPPM	36	1 (2)*
(4,4)-OPPM	48	2 (3)*

To demonstrate how OPPM may be used to remove one or more critical poles, it is useful to write the OPPM registration word in polynomial form. For the example shown in Figure 8 the registration word W(z) is

$$W(z) = (z^{-1} + z^{-2}) + (z^{-7} + z^{-8}) + (z^{-11} + z^{-12}) \\ + (z^{-18} + z^{-19}) + (z^{-20} + z^{-21}) + (z^{-25} + z^{-26})$$

This can readily be factorised in to two components.

$$W(z) = (z^{-1} + z^{-7} + z^{-11} + z^{-18} + z^{-20} + z^{25})(1 + z^{-1}) \\ = W_{reg}(z) W_{pulse}(z)$$

Where the first term $W_{reg}(z)$ contains the positional information of the registration word while the second term $W_{pulse}(z)$ describes the pulse shape of the OPPM symbol but contains no important information as such.

If it is assumed that it is desirable to remove a critical pole at z=a for the pre-distortion filter this can be achieved by placing a zero at z=a in the W(z) registration word. Since W(z) does not convey phase information, the phase of the pulse shape $W_{pulse}(z)$ can be changed without affecting the amplitude information of W(z). In particular, provided that |a| is approximately equal to one, we can re-write $W_{pulse}(z)$ to contain a zero at z=a.

$$W_{pulse}(z) = (1 + az^{-1})$$

The amplitude information of W(z) remains unaffected by this modification. Ideally, |a| should be approximately equal to one but the magnitude of a maybe as small as 0.9 without significantly affecting W(z). Hence W(z) and F(z) now contain a coincident pole zero pair that maybe removed.

If (4,3)-OPPM is used, it is possible to remove another critical pole from the pre-distortion filter but the pulse shape can no longer be guaranteed to have a magnitude less than unity. This can be seen more clearly if we expand $W_{pulse}(z)$ for the case of two critical zeros at z=a and z=b.

$$\begin{aligned} W_{pulse}(z) &= (1 + az^{-1})(1 + bz^{-1}) \\ &= 1 + (a + b)z^{-1} + abz^{-2} \end{aligned}$$

As both a and b will have magnitudes close to unity, it is possible for the second term to have a magnitude as large

as two. To transmit such a pulse shape will require a corresponding back off in transmitter power to avoid any signal clipping at the transmitter.

By using (4,4)-OPPM however, it is possible to place zeros at z=a and z=b and maintain a maximum pulse shape magnitude of unity. This can be seen by expressing the pulse shape component $W_{pulse}(z)$ as;

$$W_{pulse}(z) = (1 + az^{-1})(1 + b^2 z^{-2})$$

It can be seen by inspection of the above equation that a and b are going to be approximately unity.

It is possible to combine the root rotation and OPPM techniques to provide a maximum number of poles to be removed and in the table the figure in brackets is the number of poles which may be removed by using both techniques. The figure without brackets is that which may be removed by using the OPPM technique only.

The invention may be performed using other PPM arrangements, for example the use of higher-order PPM schemes, such as 8-PPM or 16-PPM has advantages. A higher-order PPM scheme results in a contention word with a greater number of root positions, so allowing critical filter poles to be cancelled more accurately. However, the increased number of root positions does increase the computational complexity of the root-finding process.

Instead of using the PPM scheme, it is also possible to use a full-response modulation scheme, such as BPSK or

QPSK, which has constant-amplitude constellation points. With these full-response schemes, the number of root positions is more restricted than with PPM schemes, and so the root-cancelling capability is less effective. In order to cancel filter poles more accurately, the contention word will need to be longer than with PPM schemes.

CLAIMS

1. A method of transmitting a predetermined data sequence to a receiver over a transmission channel comprising the steps of:

a) determining the impulse response of the channel,

b) providing a pre-distortion arrangement at the transmitter having a response that approximates to the inverse of the channel response, the pre-distortion arrangement comprising a filter having a critical pole,

c) causing a zero of the predetermined data sequence to coincide with the critical pole of the filter, and

d) cancelling the coincident pole-zero pair.

2. A method as claimed in Claim 1 in which step c) is performed by modifying the phase of the zeros of the predetermined data sequence.

3. A method as claimed in Claim 1or Claim 2 in which the predetermined data sequence comprises n chips of a pulse position modulated (PPM) symbols of length b.

4. A method as claimed in Claim 3 in which $a = 6$ and $b = 4$.

5. A method as claimed in Claim 3 or Claim 4 in which the PPM symbols are encoded in overlapped pulse position modulated (OPPM) form as (b, c)-OPPM symbols, where c is an integer greater than one.

6. A method as claimed in Claim 5 in which $c = 2$.

7. A method as claimed in Claim 5 or Claim 6 in which step c) is performed by modifying the phase of the pulse shape of the OPPM symbol so that a zero of the pulse shape coincides with a critical pole of the filter.

8. A method of transmitting a predetermined data sequence to a receiver over a transmission channel substantially as described herein with reference to the accompanying drawings.

9. A transmitter for transmitting a predetermined data sequence to a receiver over a transmission channel, the transmitter comprising a pre-distortion arrangement having a response that approximates to the inverse of the channel response, the pre-distortion arrangement comprising a filter having a critical pole removed by causing a zero of the predetermined data sequence to coincide with the critical pole of the filter and cancelling the pole-zero pair, and means for transmitting the data sequence modified by the pre-distortion arrangement.

10. A transmitter as claimed in Claim 9 in which the zero of the predetermined data sequence is caused to coincide with the critical pole by phase rotation of the zeros of the data sequence.

11. A transmitter as claimed in Claim 9 or Claim 10 in which the predetermined data sequence comprises n chips of pulse position modulated (PPM) symbols of length b.

12. A transmitter as claimed in Claim 11 in which a = 6 and b = 4.

13. A transmitter as claimed in Claim 11 or Claim 12 in which the PPM symbols are encoded in overlapped pulse position modulated (OPPM) form as (b,c)-OPPM symbols, where c is an integer greater than one.

14. A transmitter as claimed in Claim 13 in which $c=2$.

15. A transmitter as claimed in Claim 13 or Claim 14 in which the phase of the pulse shape of the OPPM symbol is modified so that a zero of the pulse shape coincides with a critical pole of the filter and the filter characteristic is modified by cancelling the pole-zero pair.

16. A transmitter for transmitting a predetermined data sequence over a transmission channel, the transmitter being substantially as described herein with reference to the accompanying drawings.

The Patent Office

INVESTOR IN PEOPLE

Application No: GB 0106604.2
Claims searched: 1 to 16

Examiner: Frederick Fee
Date of search: 10 December 2001

Patents Act 1977
Search Report under Section 17

Databases searched:

UK Patent Office collections, including GB, EP, WO & US patent specifications, in:

UK Cl (Ed.S): H4P

Int Cl (Ed.7): H04L, H04B

Other: On-line: WPI, EPODOC, JAPIO

Documents considered to be relevant:

Category	Identity of document and relevant passage	Relevant to claims
	None	

X	Document indicating lack of novelty or inventive step	A	Document indicating technological background and/or state of the art.
Y	Document indicating lack of inventive step if combined with one or more other documents of same category.	P	Document published on or after the declared priority date but before the filing date of this invention.
&	Member of the same patent family	E	Patent document published on or after, but with priority date earlier than, the filing date of this application.